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Effect of an integrated control strategy for schistosomiasis japonica in the lower reaches of the Yangtze River, China: an evaluation from 2005 to 2008

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Abstract

Background: Schistosomiasis japonica remains a major public health concern in China. There are many interventions implemented to control the transmission of the disease. The purpose of the present study was to investigate the effects of an integrated control strategy for schistosomiasis control.

Methods: An integrated control strategy for schistosomiasis japonica with emphasis on removing cattle from snail-infested grasslands, providing farmers with mechanized farm equipment, improving sanitation by supplying tap water and building lavatories and latrines and providing boats with fecal-matter containers was implemented in 107 villages of the lower reaches of the Yangtze River, Jiangsu Province, China, during a 32-month period from May 2005 to 2008, and the effectiveness was investigated.

Results: Following the effects of the comprehensive control, the snail habitat, infected snail habitat, snail infection rate, and *S. japonicum* prevalence in both humans and livestock all appeared a declining trend year by year, with reductions of 47.88%, 94.29%, 92.55%, 96.94%, and 100% compared with those before the comprehensive control. In addition, all of the 17 counties achieved the infection control in 2007, and 7 reached the criteria of transmission control in 2008. The confirmed snail habitats reduced from 107 to 20, and the acute infections have also been controlled for 2 successive years since 2007.

Conclusions: The integrated control strategy for schistosomiasis japonica is effective to control the transmission of *S. japonicum*.

Keywords: Schistosomiasis, *Schistosoma japonicum*, *Oncomelania hupensis*, Integrated control, Effect evaluation, The Yangtze River

Background

Human infection by the blood-fluke *Schistosoma japonicum* (Platyhelminthes: Trematoda) remains a major public health concern in the People's Republic of China, the Philippines, and parts of Indonesia [1-6]. In China, concerted control effects since the 1950s have dramatically reduced the number of the areas endemic for the parasite as well as the burden of disease among humans

[7-10]. Nevertheless, in the remaining core endemic regions, mainly located along the middle and lower reaches of the Yangtze River and some mountainous areas of provinces of Yunnan and Sichuan, over 0.7 million people are estimated to be infected, with a further 30 million at risk of infection [11]. And currently in China, more than 80% of all human *S. japonicum* infections are concentrated in the marshland and lake regions of Jiangsu, Jiangxi, Anhui, Hunan and Hubei provinces where the interruption of transmission has been proved particularly difficult to be achieved [12,13].

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Jiangsu province is located in the lower reaches of the Yangtze River in the east of China. Following the effect of flood of the upper reaches of the Yangtze River during the annual monsoon season [14,15], the marshlands along the Yangtze River operate in a “winter-land, summer-water” cycle, and vast grass-covered marshlands emerge after floodwaters recede, resulting in ideal breeding sites for *Oncomelania hupensis* survival and reproduction [16-18]. Historically, Jiangsu province suffered from a high prevalence of schistosomiasis japonica. After more than two decades of active comprehensive control with an emphasis on snail control by means of environmental improvement and mollusciciding, the province achieved the transmission control of the disease in 1976 [9,10,19]. Since the middle 1980s, the global strategy of schistosomiasis control has shifted from transmission control to morbidity control [20], following the development of the highly effective and safe schistosomicidal agent praziquantel [21,22]. In Jiangsu province, the praziquantel-based control strategy has been implemented on a large scale in all endemic areas since the late 1980s [23], particularly during the period of World Bank Loan Project for Schistosomiasis Control [24], which resulted in reduced morbidity caused by the parasite [25]. However, following the termination of the World Bank Loan Project for Schistosomiasis Control and the repeated flooding by the Yangtze River in the 1990s [15,16,19,26,27], acute human schistosomiasis cases were detected again and the area inhabited by infected *O. hupensis* snails started to increase [25,28]. Furthermore, surveillance studies suggest that chemotherapy-based programs, even those in combination with large-scale mollusciciding against snails, are unlikely to have much further impact upon prevalence levels among humans [11,12].

In 2005, the Jiangsu province proposed two goals for schistosomiasis control. First, by 2007, all of the 22 counties that were endemic for *S. japonicum* reached the criteria for infection control, and more than 50% of the counties reached the criteria for transmission control or transmission interruption. Second, by 2010, all of the schistosome-endemic counties reached the criteria for transmission control [29,30]. To achieve these two targets, since May, 2005, the Jiangsu province, according to the current local schistosomiasis epidemics, implemented an integrated control strategy for schistosomiasis japonica. Particularly emphasized were removing cattle from snail-infested grasslands, providing farmers with mechanized farm equipment, improving sanitation by supplying tap water and building lavatories and latrines, providing boats with fecal-matter containers, and other routine interventions like health education, snail control, and praziquantel-based synchronous chemotherapy for both infected humans and livestock [31].

In the present study, we describe the implementation of the integrated strategy and investigate the effectiveness of the strategy adopted in 107 villages from 17 counties along the lower reaches of the Yangtze River, Jiangsu province, during a 32-month period from May, 2005 to December, 2008.

Methods

Study area

A total of 107 villages from 17 counties of Jiangsu province were included in the current study (Figure 1), where *S. japonicum*-infected snails were detected during the period between March, 2003 and April, 2005. The study areas had a total of 273,533 residents, 1323 bovine (including 971 cattle), 4379 sheep, 142 sluices and 103 river courses. Currently, 319 cases with advanced schistosomiasis were found and 977 cases with chronic schistosomiasis were identified from 2001 to 2005 [32]. From 2003 to April, 2005, a total of 266 sites infested with infected snails were detected in the study areas, with areas of 2877.85 hm².

Interventions to control sources of *S. japonicum* infection

During the study period from May, 2005 through 2008, considering that cattle were identified as the primary source of *S. japonicum* [33,34], all the 971 cattle were replaced with small farm machines to eliminate cattle as a source of infection to snails. And 8554 domestic animals (including bovine, sheep, pigs, dogs) were raised in pens to reduce or avoid the contamination of the grassland. To reduce humans as a source of infection in snails, the following interventions were implemented to attempt to reduce the transmission. A total of 725 households were supplied with tap water, 1907

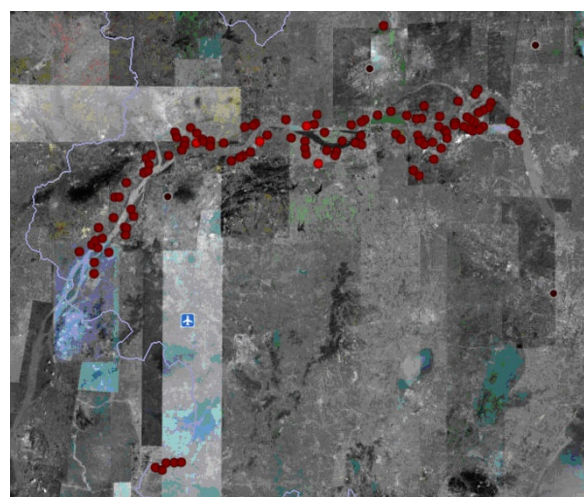


Figure 1 Location of the study villages in the lower reaches of the Yangtze River, Jiangsu province, China.

fecal-matter container were supplied to the mobile boat fishermen and 75129 public latrines with three-cell septic tanks were constructed, so that human feces could be disposed of on land instead of directly into the lake.

Comprehensive control of snail habitats

A comprehensive approach was employed to control snails by mollusciciding together with environmental modification. Over the 32-month study period, a total of 12671.52 hm² of snail habitats were treated with molluscicides like niclosamide. Environmental improvement such as constructing fish ponds, digging new ditches, building fruit trees and filling of infested areas was carried out by health sections, together with water resources development and agricultural and forestry projects. During the study period, 4173.55 hm² of snail habitats underwent environmental modification, 44 sluices were re-built for prevention of snail spread, and 217.4 km long river banks were hardened using concrete.

Other routine control interventions

During the study period in all villages, some routine control activities were undertaken to control *S. japonicum* infection. These interventions included synchronous chemotherapy for both infected humans and livestock, and health education focusing on avoidance of snail-infested areas and associated lake water. From 2005 to 2008, 0.21 million people including 3922 boat fishermen were examined for schistosomiasis infections using serological screening with dipstick dye immunoassay (DDIA) [35-37], followed by the miracidium hatching test [32], 7264 high-risk populations were treated with praziquantel at a single oral dose of 40 mg/kg for expanded chemotherapy, and 0.55 million persons received health education by means of cartoons, videotapes, comic-style booklets, billboards, sessions and other media.

Infection in humans and livestock

During the period of schistosomiasis non-transmission of each year, more than 90% of individuals aged 6-60 years in each study village were screened for *S. japonicum* antibodies using the DDIA technique [35-37], and the miracidium hatching test was employed in those seropositive individuals for definitive diagnosis of infections [32]. The miracidium hatching test was used for detecting infection of *S. japonicum* in livestock [32]. The seroprevalence and parasitological prevalence of *S. japonicum* were recorded and calculated.

Effect evaluation of snail control

From 2005 to 2008, once-yearly (from April to May) a snail survey was carried out by means of a systematic

sampling technique along the river banks and in marshland and ditches around the study villages [32]. A snail collection device made of iron wire and consisting of a 0.1 m² square frame was placed every 20 m along the survey line. All snails within the frame were collected, enumerated, crushed and examined for *S. japonicum* infection using a microscopy. Various indices were recorded, namely snail habitats, density of living snails, density of infected snails and the snail infection rate.

Ethical approval

This study was approved by the Ethics Review Committee of Jiangsu Province, Jiangsu Institute of Parasitic Diseases, and National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention.

Statistical analysis

All data were entered in Excel (Microsoft Corporation; Redmond, WA, USA) and all statistical analyses were performed using the statistical software Statistical Package for the Social Sciences Version 13.0 (SPSS Inc., Chicago, IL, USA). Differences of proportions were tested for statistical significance with the chi-square test. A *P*-value < 0.05 was considered significant.

Results

S. japonicum infections in humans and livestock

The prevalences of *S. japonicum* were 0.57%, 0.2%, 0.13%, 0.03%, 0.01% and 0.02%, respectively in humans, and 0.4%, 0.37%, 0.1%, 0.04%, 0.01% and 0 in livestock from 2003 to 2008 (Table 1, Figure 2). Between 2003 and 2008, the annual acute infections were 116, 38, 11, 2, 0 and 0, presenting a significant declining trend. After the implementation of the integrated schistosomiasis control strategy, the seroprevalence, parasitological prevalence and prevalence of *S. japonicum* in humans reduced by 81.17%, 90.35% and 96.94%, respectively, and 100% of reductions in prevalence of livestock and bovine and acute infections were also achieved (Table 2), in comparison with those rates before the implementation of the integrated strategy (all *P* values < 0.01).

S. japonicum infections in snails

From 2003 to 2008, the confirmed snail habitats out of all field survey sites were 80, 90, 60, 44, 41 and 20, respectively. The total area of snail habitats was reduced from 7243.06 hm² to 3775.26 hm², and the area where infected snails were detected decreased from 2173.93 hm² to 124.19 hm² over the study period. The prevalences of *S. japonicum* infections in the snails collected from 2003 to 2008 were 0.31%, 0.16%, 0.13%, 0.21%, 0.09% and 0.02%, respectively (Table 3). After the implementation of the integrated strategy, the snail host and *S. japonicum* infections in snails were controlled

Table 1 *S. japonicum* prevalence in humans and livestock and acute infections in the 107 villages in a pilot control program of Jiangsu Province, from 2003 to 2008

Year	No. people examined	No. infected people	Prevalence of residents (%)	No. acute infections	No. livestock detected		No. infected livestock		Prevalence of livestock (%)	
					Total	In: bovine detected	Total	Infected bovine	Total	In: bovine
2003	140868	802	0.57	116	9849	5424	39	35	0.4	0.65
2004	237443	478	0.2	38	9526	4956	35	15	0.37	0.3
2005	229979	298	0.13	11	15928	3900	16	8	0.1	0.21
2006	264357	90	0.03	2	16170	2724	6	3	0.04	0.11
2007	305719	45	0.01	0	14215	2198	2	2	0.01	0.09
2008	252323	44	0.02	0	13705	1604	0	0	0	0

significantly, with reductions in snail habitat, infected snail habitat and snail infections of 47.88%, 94.29% and 92.55%, respectively (Table 2).

Up to 2007, all of the 17 counties achieved the infection control. In 2008, 7 out of the 17 counties reached the criteria of transmission control, and *S. japonicum*-infected snails were eliminated in 60 out of the 117 study villages.

Discussion

Historically, Jiangsu Province suffered from a very high prevalence of schistosomiasis japonica in China, 10 out of the 13 cities of the province were endemic for *S. japonicum*, with accumulated schistosomiasis cases of more than 2.5 million, and accumulated snail habitats of about 1.5 billion m² [7,9,10,38]. During the past 5 decades, the Jiangsu Provincial government placed a high priority on the control of schistosomiasis and had carried out many control programs. These effective interventions have resulted in substantial reductions in the prevalence of *S. japonicum* in humans and livestock, and snail and infected snail habitats [28,29]. The remaining core endemic areas were mainly located in the marshlands along the Yangtze River and those rivers that connect with the Yangtze River [39]. In terms of the present schistosomiasis epidemics, how to highlight

the control emphasis and then implement the effective interventions is a key point to promote further control programs. In 2004, the Jiangsu Provincial government formulated the Mid- and Long-term Plan for Prevention and Control of Schistosomiasis in Jiangsu Province (2005-2010) based on control of schistosomiasis in Jiangsu section of the Yangtze River, and initiated an integrated control program for schistosomiasis in all villages that are endemic for *S. japonicum* since 2005 [31,40,41]. The strategy focused on 117 villages of the province where *S. japonicum*-infected snails were found. Through the field implementation of the integrated schistosomiasis control, significant control effects were

Table 2 Comparison of the control effects before and after the implementation of the integrated schistosomiasis control strategy in 107 villages of Jiangsu Province

Indicator	Before the implementation of the integrated control strategy	After the implementation of the integrated control strategy	Reductions (%)
Snail habitats (hm ²)	7243.03	3775.26	47.88
Infected snail habitats (hm ²)	2173.93	124.19	94.29
No. villages with infected snails	80	20	75
Seroprevalence in humans (%)	4.5	0.85	81.17
Parasitological prevalence in humans (%)	0.06	0.01	90.35
Prevalence in humans (%)	0.57	0.02	96.94
Acute infections	116	0	100
Prevalence in livestock (%)	0.4	0	100
Prevalence in bovine (%)	0.65	0	100
Snail infections (%)	0.31	0.02	92.55

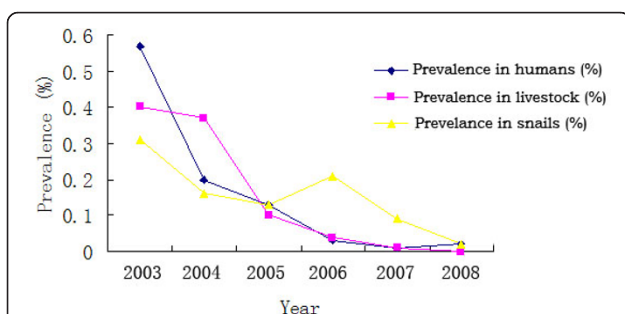


Figure 2 Evolution of average *S. japonicum* prevalence in humans, livestock and *O. hupensis* snails in the study villages from 2003 to 2008.

Table 3 Changes of *Oncomelania hupensis* snail in the 107 villages in a pilot control program of Jiangsu Province, from 2003 to 2008

Year	Snail habitat (hm ²)	Infected snail habitat (hm ²)	No. snails dissected	No. infected snails	Infection rate of snails (%)	No. villages with infected snails
2003	7243.06	2173.93	585298	1808	0.31	80
2004	7625.23	2130.53	597783	950	0.16	90
2005	7701.07	1767.70	551843	705	0.13	60
2006	5887.96	1444.34	344905	735	0.21	44
2007	4487.75	802.73	296868	254	0.09	41
2008	3775.26	124.19	295384	68	0.02	20

achieved. In addition, the new strategy provided a novel pattern for control of schistosomiasis, namely integrating all kinds of resources and boosting the whole villages.

With the gradual decline of schistosomiasis, the Chinese government has implemented a stratified control pattern based on villages with different intensities of *S. japonicum* infection [33,34]. However, the stratification is mainly based on the infection rates of *S. japonicum* in both humans and livestock, which is increasingly meaningless in areas with low infection intensities [42,43]. Since 2005, we targeted the 107 villages of the province (belonging to 17 counties) where infected snails were detected between March, 2003 and April, 2005, and carried out a comprehensive control strategy for schistosomiasis japonica in the field for a successive four years. Following the effects of the comprehensive control, the snail habitat, infected snail habitat, snail infection rate, and *S. japonicum* prevalence in both humans and livestock all appeared a declining trend year by year, with reductions of 47.88%, 94.29%, 92.55%, 96.94%, and 100% compared with those before the comprehensive control. In addition, all of the 17 counties achieved the infection control in 2007, and 7 reached the criteria of transmission control in 2008. The confirmed snail habitats reduced from 107 to 20, and the acute infections have also been controlled for a successive 2 years since 2007. It is indicated that the integrated schistosomiasis control strategy with emphasis on elimination of the snail host could promote the control progress in those regions with low infection intensities.

Schistosomiasis control is a systematic project involving sectors of water conservancy, agriculture, forestry, health, etc [44]. The effects of combination of resources from different sectors on schistosomiasis control remains unclear, and the better utilization would be of great value for further promotion of the control achievements. The present study showed, under the application of the same mollusciciding, the snail habitats kept vast, the prevalence in humans and livestock reduced but still maintained in a high level, and the acute infections were not effectively controlled from 2003 to April, 2005. By

contrast, since May, 2005, when the government initiated the integrated control program, the snail habitats reduced dramatically, the prevalence in humans, livestock and snails quickly decreased to a low level, and the acute infections were eliminated. In 2006, a higher snail infection rate was observed compared with those in 2004 and 2005, this was because mollusciciding was not effectively implemented in 1 of 107 villages, leading to a failure in the control of snail control. However, all of the other indicators like the snail habitat, infected snail habitat, number of villages with infected snails, reduced compared with those in both 2004 and 2005.

Conclusions

The integrated control strategy for schistosomiasis japonica described here is effective to control the transmission of *S. japonicum*, and it established a new schistosomiasis control pattern that integrates multi-sector resources. Further studies should be carried out to investigate the effects of the strategy in other schistosome-endemic regions of China with comparable ecological, cultural and socio-economic characteristics.

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Authors' contributions

LPS and YSL conceived and designed the study. LPS collected the data. LPS, WW, ZXT, QBH, GJY, KY, JRD implemented the study. LPS and WW carried out the statistical analysis and prepared the manuscript. YSL revised and finalized the manuscript. All of the authors read and approved the final version of the manuscript.

Competing interests

The authors declare that they have no competing interests.

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